Modifications made to the Piper PA-28 Arrow for the spin tests include a tail-mounted spin-recovery parachute system and a door with explosive bolts. The discontinuous drooped leading edge installed on the outboard wing section runs from the 53% to 96% semispan locations.

Business Flying

Wing Alteration Boosts Spin Resistance

By David M. North

Langley AFB, Va.—National Aeronautics and Space Administration has developed and test flown a wing leading edge modification on a Piper Aircraft Arrow that increases the spin resistance of general aviation aircraft.

The modified research aircraft used for spin tests was flown by this AVIATION WEEK & SPACE TECHNOLOGY pilot in recent evaluation flights. The two demonstration and evaluation flights were flown from NASA’s Langley Research Center here to the NASA Wallops Island Flight Center with space agency test pilot Philip W. Brown.

Prior to the flight, Brown detailed some of the changes made to the single-piston-engine aircraft by NASA for the spin evaluation program. The modified aircraft is a hybrid never in production at Piper. It has a fuselage 27 in. longer than a standard Arrow, a T-tail and a tapered wing from an Arrow 3.

The primary change made to the PA-28RX test aircraft by NASA to enhance its spin resistance was the drooping of the 60 series wing’s leading edge from the 53% to the 96% semispan locations. The 2-deg. of washout chordwise across the tapered panel of the basic Arrow wing was increased to 8.5 deg. for the modified outboard leading edge configuration. The PA-28 has a twisted and tapered wing.

Other modifications made for the spin program included the installation of a tail- mounted spin-recovery parachute system and a door with explosive bolts cut into the left side of the aircraft. The aircraft’s right side door is retained and used for normal access to the cabin.

The test equipment mounted on the Arrow during the spin program included wingtip booms to measure and record true airspeeds and flow angles ahead of each wing tip, linear accelerations and angular rates along and about the body axes and control positions and forces. Engine power parameters, altitude and dynamic pressures also were recorded on the aircraft monitoring systems.

On-board data systems were supplemented by ground video and movie camera coverage and by wing-tip and cockpit-mounted cameras. The data for each entry into a spin maneuver and recovery were time-correlated with pilot comments made via the radio to the ground.

I took the left seat and Brown the right seat prior to taking off for the Wallops Island instrumented test range. The Arrow was flown at 7,000 ft. for the approximately 40-min. flight to the area above the NASA test facility. Before starting each stall sequence, Brown demonstrated the entry and recovery procedure to be used in performing the maneuvers.

Twenty stalls were accomplished during two separate flights. Between the two flights, Brown and I took a break at the Wallops Island Flight Center before returning to Langley AFB.

The entrance into the stall sequence was accomplished by a number of different methods. During the first 11 stalls, the entrance into the stall was by a slow deceleration, both with power on and at idle. Also during this sequence, the left and right rudders were introduced near the stall speed of the aircraft. The next four stalls were achieved while in a turn and
with power at the maximum cruise setting. The remaining stalls had different speeds of entry, but were accomplished primarily with prospin control input at the point of stall.

All of the stalls accomplished with Brown in the modified Arrow, both with and without prospin controls, were characterized by one result: the aircraft did not enter a spin in any of the situations. Brown said it was possible to get the aircraft into a spin only with prolonged, aggravated control inputs.

**Full-Aft Yoke**

One such method, Brown said, was to zoom the aircraft up to a near 60-deg. nose-high attitude at full power, and then to keep pulsing prospin aileron and rudder controls with the yoke in the full aft position. Even with this method, Brown said, the result of the maneuver was only sometimes a spin.

The only method found to achieve a nonrecoverable spin from a 1g stall in the modified Arrow was to move the center of gravity of the aircraft beyond the approved loading envelope and then to use maximum power in the stall sequence.

During 255 attempts to spin the basic Arrow before it was modified with the outboard wing droop, 224, or 88%, resulted in a spin. After the wing modification, 236 attempts to spin the aircraft were flown, and only during 12 stalls, or 5%, was the pilot able to enter a spin.

National Aeronautics and Space Administration pilots discovered that the Piper aircraft had a post-stall wing rock, prior to reaching the full aft yoke position, which tended to develop into an uncontrollable roll to the side during the initial spin tests of the unmodified Arrow. The unmodified aircraft would spin readily from a 1g entry with power on and power off. With the application of full aft yoke, followed by prospin rudder control and neutral aileron control, the Arrow would spin at about a 43-deg. angle of attack. The stall angle of attack was close to 18 deg.

**Slow Deceleration**

Brown demonstrated the first two stalls at 7,000 ft. Both were with a slow deceleration, with power off on the first stall and power on in the second. I was able to observe the flow tufts mounted on the top of the Arrow's wing. Brown was able to control the aircraft with the ailerons as the Arrow stalled at approximately 70 mph., and at the stall the flow tufts indicated attached airflow on the outboard section of the wing. With the power near idle, the aircraft was descending at about 1,500 fpm. with the yoke still full aft and the nose attitude increasing and decreasing as the elevator became more effective at the higher speeds.

The second stall performed by Brown

Aviation Week & Space Technology, July 23, 1984
had essentially the same results with the power at maximum. He was easily able to control the aircraft to keep the wings level even at the slower stall speeds afforded by the engine power.

I performed the next two stalls—with power off and with my feet on the floor. As with the stall performed by Brown, I was able to maintain wings level with control input only to the ailerons and with the yoke in the full aft position. In some cases it required full ailerons and some time before the aircraft responded to the control input.

**Rudder Application**

A stall series then was performed with the application of rudder before reaching the 65-70-mph. stall speed. In the first two stalls, the right rudder was used from one-half to three-quarters of its full travel. The input of the right rudder is less demanding because of the need for right rudder application as the aircraft is slowing. During these two stalls, with the yoke full aft, as the aircraft stalled the rudder was initially effective and imparted a roll to the left. As the nose started to fall through because of the lack of elevator effectiveness, the ailerons became effective, and I was able to counter rudder input with aileron control to return the aircraft to wings level.

The same response to rudder and aileron controls was evident during the input of left rudder during the stalls. The only difference was that it took the Arrow slightly longer to respond to the aileron input to bring the wings to the level position. Maximum yaw during these stalls was approximately 20 deg.

The next four stall sequences were entered with power on and in a turn, as might be expected during an approach to landing or in a possible runway overshoot situation. One of the motivating factors in NASA’s continued research into improving the stall and spin resistance of aircraft has been provided by analysis of general aviation accidents.

**Fatal Accidents**

Approximately 25% of all fatal general aviation accidents has been traced to stall and spin as the probable cause. The study found that 40% occur during the in-flight phase, 24% during takeoff and 36% in the landing phase. The median flight time of pilots involved is 400 hr., and the accident is usually caused by distraction.

In all of the power-on accelerated stalls, the Arrow was fully controllable with aileron through the stall and recovery in level flight. At the stall, in approximately 2g to 3g flight, the aircraft wanted to spiral in the direction of the turn, but with aileron control the Arrow was quickly brought back to wings-level flight with little loss of altitude.

The next five stall sequences were ac-
Higher angle of attack afforded by the modified leading edge for the outboard section of the wing is indicated in this graph. The sharp drop in resultant force for the basic wing occurs at approximately 18-deg. angle of attack. In the modified aircraft, the buffet and stall still occurs at 18 deg., but the lift of the outer panel continues to increase, giving complete aileron control to the pilot to counter a roll-off to the side and possible spin.

complished with prospin input. Brown did the first two, and I flew the remaining three maneuvers. Brown introduced full left rudder and full aft stick at the stall. The Arrow rolled to the right in the power-on maneuver. Roll rate during the spiral reached a maximum of 30 deg./sec. As soon as the speed of the aircraft had increased during the spiral, Brown was able to counter the turn with opposite aileron and to fly the Arrow out of the spiral after reaching a maximum speed of 150 mph.

The remaining four stall sequences yielded much the same result as the first stall and spiral recovery, both with power on and power off. At the stall and with prospin control inputs, the Arrow would enter a lazy spiral with an angle of attack below the aircraft's stall angle of attack. As soon as the speed started to increase as the aircraft's nose fell through the horizon, aileron control was effective in recovering the aircraft from its spiral with a minimum loss of altitude. In all of these spin attempts, the lowest speed recorded on the monitor tapes was close to 60 mph.

Highest angle of attack recorded during all of the stalls was approximately 20 deg. The unmodified inboard wing section stalled at approximately an 18-deg. angle of attack and provided the slight buffet warning and then the high rate of descent, while the modified section of the outboard wing did not stall and provided aileron control during the stall and recovery.

Another NASA test pilot and head of aircraft operation, James M. Patton, said the stall maneuver with the flaps down was similar to that with the flaps up. The only difference between the two configurations, Patton said, was that with flaps down, the stick force gradient tended to lighten near the stall.

I also noted during the stall sequences that the time between the stall and application of prospin controls and the departure to a spiral was much longer than would have been the case in a standard Arrow.

Brown said that in initial tests with the unmodified Piper aircraft, it took 4 sec. from the application of prospin control inputs to the departure point. In the modified aircraft, the time to reach the departure point, in the few instances that the aircraft did spin, was almost 12 sec.

In a report done by the staff at the Langley Research Center on the use of the modified wing leading edge to enhance spin resistance, the following results were noted:

- Modification increased stall angle of attack of the outer wing to approximately double the stall angle of attack of the basic wing.
- The modified aircraft had improved stall behavior and a high degree of spin resistance compared with the basic aircraft.
- Spin resistance had been related to both the maximum attainable outer wing panel angle of attack and the yaw rate generated by the aircraft during maneuvers.
- Spin resistance had been related to center of gravity position, power level and dynamic effects through their influence on the maximum angle of attack attainable at the outer wing panels.
- Both increasing static margin and reducing power levels increased the magnitude of dynamic effects that had to be provided by aircraft maneuvering in order to enter a spin.

Panel Modification

These results were based on the flight tests of the modified Piper Arrow and a Beech Aircraft Sundowner with a modified leading edge outer wing panel similar to that of the Piper aircraft. Earlier stall and spin tests performed with a Grumman American Yankee yielded results similar to those of the more recent flight tests (AIAA Sept. 7, 1978, p. 103).

The Yankee also was tested with a fully drooped leading edge and, although the aircraft was found to be harder to stall, when it did stall and then spin it was found that the aircraft could get into a nonrecoverable spin.

The next step for NASA in stall and spin resistance research is to apply the modified outer wing leading edge to other types of airfoils to determine whether wind tunnel and flight tests will yield the same results as previous tests. NASA is negotiating with the U.S. Navy to start a joint program of spin resistance modification on a Beech T-34C.

Leading Edge Droop

National Aeronautics and Space Administration officials see the Navy program as affording a possibility to modify a 230 series airfoil with a leading edge droop that could be bolted on and easily removed from the turboprop training aircraft. The leading edge droop could be bolted on the T-34C's wing for normal flights to enhance spin resistance and then removed from the tandem seat trainer for acrobatic and spin flights.

Testing on the leading edge droop modification to date has shown that the modified aircraft loses little performance. The earlier flight tests on the Yankee showed that the aircraft lost 1-2 kt. in cruise speed but gained in climb performance. The same results are expected of the modified Navy T-34C, Joseph Stickle, chief of Langley's Low-Speed Aerodynamics Div., said. As with many of its research pro-

148 Aviation Week & Space Technology, July 23, 1984
Oil flow studies of a one-sixth scale model of the Piper Arrow were conducted at the University of Maryland by NASA. The photo above is of an unmodified aircraft at a 30-deg. angle of attack. Note the separation of the oil flow and the spanwise flow of the boundary layer. Separation does not progress spanwise on the modified outer wing panels in the photo below. The vortex type oil flow starts at the break in the modified wing, which seems to prevent outward progression of the separated flow. Angle of attack during this test is 35 deg.
programs, NASA is attempting to prod general aviation aircraft manufacturers into accepting its data from the spin-resistance program. The agency has had test pilots from Beech, Cessna and Piper Aircraft fly the modified aircraft but has received no commitment from the manufacturers to adopt the modification to existing aircraft. Cessna, however, is looking at the leading edge change for possible installation on the newest version of the P210.

"With the leading edge modification," Stickle said, "you get so much in increased safety margins for so little cost and performance loss. One of the ways we might be more able to sell the concept of spin resistance is if we could prompt the FAA to issue a certification credit for added spin resistance. We are exploring that possibility with the FAA now."

**Laminar Flow**

The next step beyond testing existing wings with the leading edge modifications, Stickle said, is to develop a wing with a high degree of natural laminar flow and to incorporate the outboard wing changes. Both programs are being conducted at the NASA research center here.

The space agency has built a generic wing scale-model that has a high degree of natural laminar flow and has modified the wing's leading edge with the discontinuous droop. The model has been tested in the NASA wind tunnel here recently. NASA is in a cooperative program with Cessna for wind tunnel tests to be conducted this year on a modified natural laminar flow wing and for flight tests of the P210 to begin in mid-1985.

"The true payoff for all of this research," Stickle said, "would be a wing with a high natural laminar flow capability combined with enhanced spin resistance. Doing that increases the performance of the aircraft as well as improving the safety."

**Porous Edge**

Another means of achieving a higher degree of natural laminar flow, that of using a glycol and water solution excreted through a porous leading edge, also has been tested by NASA. The most recent tests were conducted with a Cessna Citation 3. The wet leading edge cuts down insect accumulation by at least 85% with the use of less than 16 oz. of fluid per flight through the lower altitudes.

The combination of the wet leading edge and the spin resistance modification has yet to be tested but is a possible future program for NASA. The space agency test flights on the Citation 3 have yet to be fully evaluated as to the effect of wing sweep, Mach number and Reynolds number on natural flow. Further tests for wing sweep and natural laminar flow are scheduled to be conducted on a Grumman F-14 later this year or next year.

Aviation Week & Space Technology, July 23, 1984